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Testing the Anomaly Mediation at the LHC

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Abstract

We consider a supersymmetric model in which gaugino masses are generated by the anomaly-mediation mechanism while scalar masses are from tree-level supergravity interaction. In such a model, scalar fermions as well as Higgsinos become as heavy as $O(10-100 \text{ TeV})$ and hence only the gauginos are superparticles kinematically accessible to the LHC. We study how and how well the properties of gauginos can be studied. We also discuss the strategy to test the anomaly-mediation model at the LHC.

1 Introduction

Anomaly mediation of supersymmetry (SUSY) breaking in a hidden to the SUSY standard-model (SUSY SM, or SSM) sector [1, 2] is very attractive, since it is the simplest mechanism for the mediation of SUSY breaking. Namely, the anomaly mediation always takes place in a generic SUSY theory and hence we do not need any extra assumption beside the presence of SUSY breaking sector to mediate the SUSY-breaking effects to the SSM sector. Without any special requirement on the Kähler potential, but just by assuming that there is no singlet field in the SUSY breaking sector, the scenario of anomaly mediation predicts the so-called split SUSY spectrum [3] where squarks and sleptons may have masses of the order $10 - 100$ TeV while the masses of gauginos are in the range of $100 \text{ GeV} - 1 \text{ TeV}$ [4, 5].^{#1}

Because of the relatively large masses of squarks we need a very precious fine-tuning of parameters to obtain the correct electroweak symmetry breaking, but on the other hand it solves many serious problems in the SSM. First of all the flavor-changing neutral current and CP-violation problems become very milder due to the large masses of squarks and sleptons. We may naturally explain no discovery of Higgs at LEP and no discovery of proton decays induced by dimension-five operators. Furthermore, the gravitino mass is also predicted at the order of 100 TeV , which makes the cosmological gravitino problems much less severe [6, 7]. In fact, it has been pointed out that the leptogenesis [8] does work in the anomaly-mediation model, since the reheating temperature T_R can be as high as 10^{10} GeV without any conflict with cosmology [9].

Although the squarks and sleptons are so heavy, the masses of gauginos may be in the accessible range to the LHC experiments. Thus, even in this model, discovery of the signals from the productions of superparticles may be possible at the LHC. More importantly, the anomaly-mediation model predicts unique mass relation among gauginos, as we will see in the following. In particular, the anomaly mediation predicts $m_{\tilde{W}} < m_{\tilde{B}} < m_{\tilde{g}}$ (with $m_{\tilde{B}}$, $m_{\tilde{W}}$, and $m_{\tilde{g}}$ being the gaugino masses of $U(1)_Y$, $SU(2)_L$, and $SU(3)_C$ gauge groups, respectively) in a large region of the parameter space [5]. In this letter, we discuss how the anomaly-mediation model can be studied at the LHC.

2 Model

Let us start our discussion by summarizing basic features of the model. As we have mentioned in the previous section, we consider the anomaly-mediation model in which all the sfermions as well as heavy Higgses and Higgsinos are heavy (of masses of the order of 100 TeV). Assuming that there is no singlet field in the SUSY breaking sector, all the gaugino masses are suppressed compared to the SUSY breaking scalar masses.

In this class of models, gaugino masses are mainly from the effect of anomaly mediation

^{#1}In this letter, we use “anomaly-mediation model” for those where gaugino masses are generated by the effect of anomaly mediation while the scalar masses are from tree-level supergravity interaction between observable-sector fields and SUSY breaking fields.

and possible radiative correction due to the Higgs-Higgsino loop [1, 10]. Then, the SUSY breaking gaugino mass parameters (at the scale of sfermion masses $m_{\tilde{f}}$) are obtained as

$$M_1 = \frac{g_1^2}{16\pi^2} (11m_{3/2} + L), \quad (1)$$

$$M_2 = \frac{g_2^2}{16\pi^2} (m_{3/2} + L), \quad (2)$$

$$M_3 = \frac{g_3^2}{16\pi^2} (-3m_{3/2}), \quad (3)$$

where g_1 , g_2 , and g_3 are gauge coupling constants of $U(1)_Y$, $SU(2)_L$, and $SU(3)_C$ gauge groups, respectively, and $m_{3/2}$ is the gravitino mass. (Hereafter, we use the convention such that $m_{3/2}$ is real and positive.) In addition,

$$L \equiv \mu \sin 2\beta \frac{m_A^2}{|\mu|^2 - m_A^2} \ln \frac{|\mu|^2}{m_A^2}, \quad (4)$$

with $\tan \beta$ being the ratio of two Higgs bosons, and m_A the mass of heavy Higgses. Thus, due to the Higgs-Higgsino loop contribution, gaugino masses may significantly deviate from the pure-anomaly-mediation relation (which is given by taking $L = 0$). However, since the natural sizes of $|\mu|$ and m_A are both of the order of the gravitino mass, the L -parameter is expected to be at most $O(m_{3/2})$. (Notice that $|L| \leq m_A$.) Consequently, with a natural choice of μ - and B_μ -parameters, Wino becomes the lightest among gauginos in a large region of the parameter space. In this case, taking account of the radiative correction due to electroweak gauge bosons, neutral Wino \tilde{W}^0 becomes the lightest superparticle (LSP) [11]. Charged Wino \tilde{W}^\pm becomes slightly heavier than the neutral one; the mass splitting is as small as $m_{\tilde{W}^\pm} - m_{\tilde{W}^0} \simeq 155 - 170$ MeV. As we will see, the smallness of the mass splitting has an important implication to the study of the anomaly-mediation model at the LHC.

We should also note that three gaugino masses depend on three parameters: $m_{3/2}$, $|L|$, and $\text{Arg}(L)$. Even so, non-trivial constraint exists among the gaugino masses. In order to see how the gaugino masses are constrained, it is instructive to approximate the physical (i.e., on-shell) gaugino masses by $M_1 - M_3$ given in Eqs. (1) – (3). Then, we can see

$$\left| \frac{10g_1^2}{3g_3^2} m_{\tilde{g}} - \frac{g_1^2}{g_2^2} m_{\tilde{W}} \right| \lesssim m_{\tilde{B}} \lesssim \frac{10g_1^2}{3g_3^2} m_{\tilde{g}} + \frac{g_1^2}{g_2^2} m_{\tilde{W}}. \quad (5)$$

Thus, once the Wino and gluino masses are fixed, upper and lower bounds on the Bino mass are obtained. (In our quantitative analysis in the following sections, we calculate the bounds more accurately by taking into account the renormalization-group effect below the sfermion-mass scale $m_{\tilde{f}}$, taking $m_{\tilde{f}} = m_{3/2}$. We have checked that the dependence on $m_{\tilde{f}}$ is rather mild; the bounds change ~ 10 GeV when $m_{\tilde{f}}$ is varied in the range $m_{3/2}/2 < m_{\tilde{f}} < 2m_{3/2}$.) It is an important test of the anomaly-mediation model to see if the gauginos satisfy the mass relation.

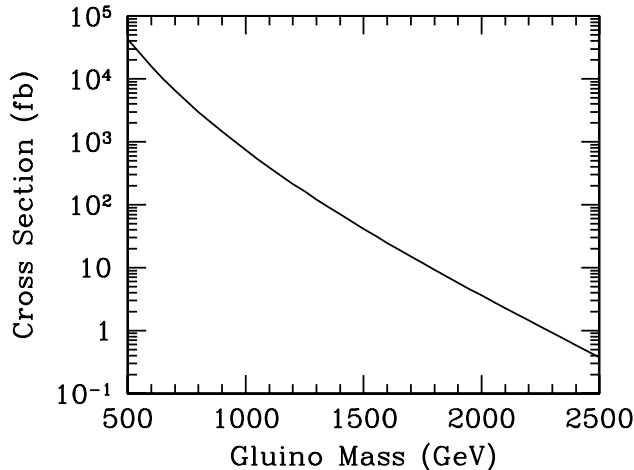


Figure 1: Cross section for the process $pp \rightarrow \tilde{g}\tilde{g}$ for $\sqrt{s} = 14$ TeV. Here the squarks are assumed to be heavy enough to be neglected.

3 Anomaly-Mediation Model at the LHC

3.1 Set up

Because the gauginos are the only superparticles kinematically accessible to the LHC, and also because an important information is imprinted in the gaugino masses, we must study the properties of the gauginos at the LHC if the anomaly-mediation model is realized in nature. In the following, we discuss how well the gauginos can be investigated at the LHC. As an example, in this letter, we consider the case where the underlying model gives $m_{\tilde{B}} = 400$ GeV, $m_{\tilde{W}} = 200$ GeV, and $m_{\tilde{g}} = 1$ TeV (which is given by $m_{3/2} \simeq 39$ TeV, $|L| \simeq 28$ TeV, and $\text{Arg}(L) = 0$). Notice that the neutral Wino is the LSP.

First, we comment on the decay of the charged Wino. Since the mass splitting $m_{\tilde{W}^\pm} - m_{\tilde{W}^0}$ is very small, \tilde{W}^\pm decays into \tilde{W}^0 emitting an extremely soft pion. Thus, it is not easy to identify the decay of the charged Wino at the LHC. In addition, since the typical decay length of \tilde{W}^\pm is $O(1-10$ cm), it is highly challenging to find the track of the charged Wino although it may not be impossible. Thus, in our main discussion, we make a conservative assumption that we cannot find the charged-Wino track; then both \tilde{W}^0 and \tilde{W}^\pm are treated as invisible particles. However, we will also discuss the implications of discovering the charged-Wino tracks.

The most important production process of superparticles at the LHC is the pair production of gluinos \tilde{g} 's: $pp \rightarrow \tilde{g}\tilde{g}$, as far as the gluino mass is about 1 TeV or smaller; in Fig. 1 we plot the cross section for this process. When $m_{\tilde{g}} \simeq 1$ TeV, for example, thousands of supersymmetric events will be available at the LHC with $\mathcal{L} = 10 \text{ fb}^{-1}$ (with \mathcal{L} being luminosity).

Once gluino is produced, it decays into a lighter gaugino (i.e., Wino \tilde{W} or Bino \tilde{B}) and standard-model fermions. If Bino \tilde{B} is produced by the decay of gluino, it decays

successively to Wino. Experimental signals strongly depend on how the gauginos decay. The decay patterns of gauginos are sensitive to the masses of sfermions and Higgsinos, and hence are not predictable. Thus, we make several assumptions for our study. For the decay of gluino, we adopt

$$Br(\tilde{g} \rightarrow \tilde{B}q\bar{q}) = 1 - Br(\tilde{g} \rightarrow \tilde{W}q\bar{q}) = 0.25, \quad (6)$$

where q denotes the standard-model quarks.

On the decay of Bino, important processes are $\tilde{B} \rightarrow \tilde{W}^\pm W^\mp$ via Bino-Wino mixing, $\tilde{B} \rightarrow \tilde{W}^0 h_{SM}$ (with h_{SM} being standard-model-like Higgs boson) via Bino-Higgsino mixing, and $\tilde{B} \rightarrow \tilde{W} f \bar{f}$ (with f being standard-model fermions) due to sfermion-exchanges. In a large fraction of the parameter space, $\tilde{B} \rightarrow \tilde{W}^\pm W^\mp$ and $\tilde{B} \rightarrow \tilde{W}^0 h_{SM}$ become the dominant decay modes.^{#2} If so, however, it is difficult to study the properties of \tilde{B} . Then, probably the anomaly-mediation model can be tested only by finding the charged-Wino track, which will be challenging, (as well as by the measurement of $m_{\tilde{g}} - m_{\tilde{W}}$, which we discuss below). If there exists a significant hierarchy between sfermion and Higgsino masses, however, the last process may dominate. In particular, if the sleptons are much lighter than Higgsino (by factor 10 or so), $\tilde{B} \rightarrow \tilde{W} l^+ l^-$ may acquire a large branching ratio. As we will see, invariant-mass distribution of $l^+ l^-$ gives an important information on the Bino mass. Thus, in order to demonstrate what we can learn from the decay mode $\tilde{B} \rightarrow \tilde{W}^0 l^+ l^-$, we consider a special case where sleptons are much lighter than the Higgsino so that the decay modes, $\tilde{B} \rightarrow \tilde{W}^\pm W^\mp$ and $\tilde{B} \rightarrow \tilde{W}^0 h_{SM}$, become negligible. For our simulation, we use

$$Br(\tilde{B} \rightarrow \tilde{W} L \bar{L}) = 1 - Br(\tilde{B} \rightarrow \tilde{W} q \bar{q}) = 0.3, \quad (7)$$

where $L = \nu, l^-$ is for the standard-model leptons.

3.2 Simulated background samples and selections

The gluino pair is produced mainly with gluon-gluon collision, and the gluino decays into \tilde{W} or \tilde{B} with two or four high p_T jets. Therefore the missing transverse energy, \cancel{E}_T , carried away by two Winos plus four high p_T jets is the leading experimental signature (defined as “no lepton mode”). Also lepton pair from the decays of \tilde{B} , four-jet and \cancel{E}_T is the next leading signature of the signal (defined as “dilepton mode”). Fraction of the event with dilepton depends strongly on the decay branching fraction, $Br(\tilde{g} \rightarrow \tilde{B}q\bar{q}) \times Br(\tilde{B} \rightarrow \tilde{W}^0 l^+ l^-)$. The discovery potential will be mainly determined with the no lepton mode and the dilepton mode will be used to measure the mass difference between \tilde{W} and \tilde{B} .

The following four standard-model processes can potentially have the event topology of \cancel{E}_T with jets:

- $W^\pm + \text{jets}, (W^\pm \rightarrow \ell \nu)$
- $Z^0 + \text{jets}, (Z^0 \rightarrow \nu \bar{\nu}, \tau^+ \tau^-)$

^{#2}We thank T. Watari for a useful discussion on the Bino decay.

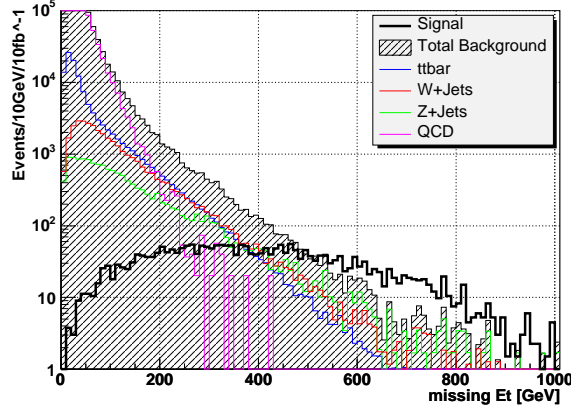


Figure 2: E_T^{miss} distribution of the SUSY signal and background processes: The open histogram shows the SUSY signal (with $m_{\tilde{g}} = 1$ TeV) and the hatched shows the sum of background distributions.

- $t\bar{t}$
- QCD jets: Heavy flavor quarks (b and c) with semi-leptonic decay and the light flavor jets with mis-measurement.

The high p_T multi-jets are key of the analysis and they should be estimated with the Matrix-Element calculation. Parton-Shower is not good approximation in such a high p_T region and the background contributions would be underestimated [12]. These background processes are generated with ALPGEN2.05 [13], and the exact Matrix-Element Calculations are applied up-to five partons. The produced 200 M events are fed into the Parton-Shower generator (JIMMY4.0/Herwig6.5 [14]) in order to evolve the QCD shower. Multiple-interaction processes are also taken into account. Matching between Matrix-Element and the evaluated Parton-Shower are also applied to remove the double counts. The detector effect is taken into account using the smearing Monte Carlo simulation of the ATLAS detector (ATLFAST [15]).

The following simple event selections are applied,

- Number of jets with $p_T > 50$ GeV is larger than or equal to 4.
- p_T of the jets are required to be larger than 200 and 100 GeV for the leading and 2nd leading jets, respectively.
- The missing transverse energy, E_T^{miss} , is larger than 300 GeV. Fig. 2 shows the E_T^{miss} distributions for the no lepton mode.
- The same flavor two leptons with $p_T > 20$ GeV are required for the dilepton mode.

The effective mass, which is define as $E_T^{\text{miss}} + \sum_{4\text{ jets}} p_T$, is a good variable to discriminate the SUSY signal from the SM background processes, and Figs. 3 show the effective mass

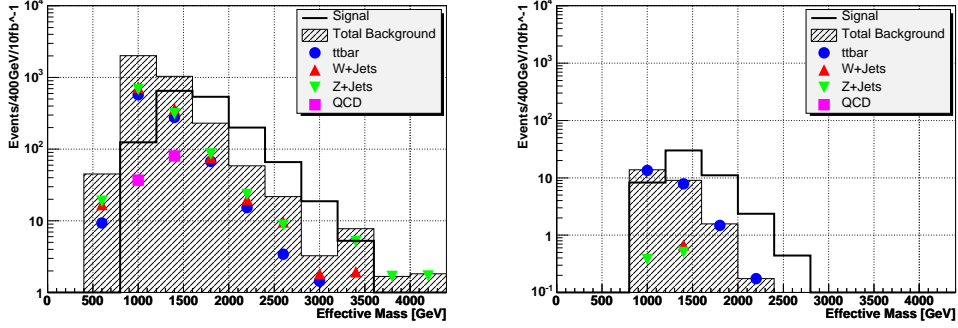


Figure 3: Effective mass distributions of the SUSY signal and background processes: No lepton mode and dilepton mode. In both figures, the open histogram shows the SUSY signal and the hatched shows the sum of background distributions. (Blue circle, red triangle, green triangle and magenta box show the top, W^\pm , Z^0 and QCD processes, respectively.)

distributions of the signal mentioned above and the SM background processes for the no lepton and dilepton modes. Three standard model processes, $W^\pm + \text{jets}$, $Z^0 + \text{jets}$, and $t\bar{t}$ contribute equally to no lepton mode, but the signal excesses (with $m_{\tilde{g}} = 1 \text{ TeV}$) will be observed in the high effective mass region. ATLAS has a discovery potential up-to 1.2 TeV with an integrated luminosity of 10 fb^{-1} . $t\bar{t}$ process is the dominant background for two lepton mode. Since flavor of the selected two leptons are independent in this case, these background processes can be removed easily using the flavor subtraction [16].

3.3 Mass reconstruction

Now, let us discuss how and how well the gaugino masses can be reconstructed. With the gluino pair production, we obtain, at the parton level, (i) four quark jets, and (ii) several charged leptons (or tau jets). The momentum distribution of the quark jets contains an information on $m_{\tilde{W}}$ and $m_{\tilde{g}}$, while that of charged leptons contains that on $m_{\tilde{B}}$ and $m_{\tilde{W}}$. Indeed, if we concentrate on the decay of single gluino: $\tilde{g} \rightarrow \tilde{W} q \bar{q}$, invariant mass of the $q \bar{q}$ system $M_{q\bar{q}}$ is required to be

$$M_{q\bar{q}} \leq m_{\tilde{g}} - m_{\tilde{W}}, \quad (8)$$

while, for the case of $\tilde{g} \rightarrow \tilde{B} q \bar{q}$, followed by $\tilde{B} \rightarrow \tilde{W}^0 l^+ l^-$, we obtain

$$M_{l^+ l^-} \leq m_{\tilde{B}} - m_{\tilde{W}}, \quad M_{l^+ l^- q \bar{q}} \leq m_{\tilde{g}} - m_{\tilde{W}}, \quad (9)$$

where $M_{l^+ l^-}$ and $M_{l^+ l^- q \bar{q}}$ are invariant masses of $q \bar{q}$ and $l^+ l^- q \bar{q}$ systems, respectively. Thus, from the invariant-mass distributions, we can extract the information on the gaugino masses.

The same selections mentioned in the previous subsection are applied to make the mass distributions for $M_{q\bar{q}}$, $M_{l^+ l^-}$ and $M_{l^+ l^- q \bar{q}}$. The integrated luminosity of 100 fb^{-1} is assumed to measure these invariant masses. The leading four jets are used to make combination of

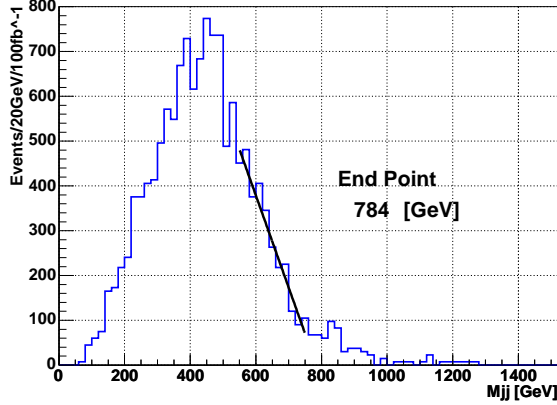


Figure 4: M_{jj} distribution for the no lepton mode.

dijets, and there are three possible combinations of four jets, (1+3, 2+4), (1+4, 2+3) and (1+2, 3+4). For example, (1+3, 2+4) means that the leading p_T and 3rd leading jets are considered to be emitted from the same gluino, and 2nd and 4th leading p_T jets have the same parent. The fractions of the correct combination are the same in the combinations of (1+3, 2+4) and (1+4, 2+3). We select the combination in which the difference between two calculated invariant masses of dijets is smaller than the other combination. On the other hand, the fraction of the wrong combination is larger in the (1+2, 3+4) combination, so this combination is used for comparison with the other combinations. The difference between two calculated invariant masses is required to be smaller than 100 GeV in order to suppress the contamination of $\tilde{g} \rightarrow \tilde{B}q\bar{q} \rightarrow q\bar{q}q\bar{q}\tilde{W}$. Fig. 4 shows the distribution of the invariant mass of dijets M_{jj} , in which the fitted endpoint using linear function is 784 ± 37 GeV (the expected endpoint is 800 GeV). Statistical error of the fitted endpoint is 5% with an integrated luminosity of 100 fb^{-1} . Jet is reconstructed with the cone algorithm (size of 0.4), and some part of the evaluated shower escapes from the cone. This is the reason why the reconstructed M_{jj} becomes smaller than parton level ($M_{q\bar{q}}$). This shift can be collected with parton-jet calibrations and the uncertainty in this calibration is finally 1%.^{#3} There is also another systematic uncertainty in the fitting procedure. The other samples with the different mass combinations are also generated, and the same selections and fitting procedure are applied. The fitted endpoints are proportional to the mass difference at parton level and consistent within an error of 5%.

Fig. 5(a) shows the M_{l+l-} distribution for the dilepton mode after the flavor subtraction [16] is performed. Clear edge is observed at the expected endpoint (200 GeV), and the statistical error of the fitted edge is 1 % with an integrated luminosity of 100 fb^{-1} . Systematic uncertainty in the absolute energy calibration is much less than the statistical

^{#3}The calibration of jet energy to parton level will be performed using $W \rightarrow q\bar{q}$ and $gq \rightarrow \gamma q$ (with g and γ being gluon and photon, respectively) events, and finally 1% level accuracy will be obtained at ATLAS detector.

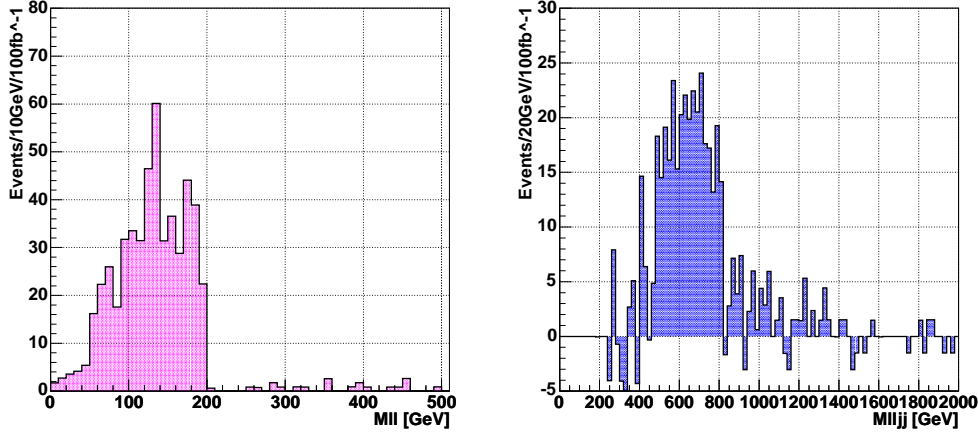


Figure 5: M_{l+l-} and $M_{l+l-q\bar{q}}$ distributions for the dilepton mode.

error.

In order to calculate the invariant mass of dijets and dileptons the corresponding two jets are selected as follows: One of the leading or 2nd leading p_T jet is selected, which is closer to the dilepton system. The distance between the dilepton and this jet is also required to be smaller than 2.0. The 4th leading jet is considered as another jet, since the p_T becomes smaller due to the smaller mass difference of \tilde{g} and \tilde{B} . The invariant mass between dilepton and the dijets are shown in Fig. 5(b), after the flavor subtraction is applied. Clear edge is still observed at 800 GeV, and the statistical error is 50 GeV.

3.4 Other possible information

So far, we have seen that some of the mass differences can be determined by the LHC. In particular, if $Br(\tilde{g} \rightarrow \tilde{B}q\bar{q})$ and $Br(\tilde{B} \rightarrow \tilde{W}^0 l^+ l^-)$ are both sizable, two mass differences can be reconstructed. Even so, the confirmation of the anomaly-mediation mass spectrum of gauginos is not straightforward because the following questions, which are crucial to test the anomaly-mediation model, are not answered yet.

First, we have seen that the information on mass differences is obtained from the invariant-mass distribution of jets and leptons. However, it is still an open question how the masses of gauginos can be determined. In addition, one should note that the event shape from the decay chain $\tilde{g} \rightarrow \tilde{B}q\bar{q}$ followed by $\tilde{B} \rightarrow \tilde{W}^0 l^+ l^-$ (or $\tilde{B} \rightarrow \tilde{W}^\pm l^\mp \nu$) is hardly distinguished from that from $\tilde{g} \rightarrow \tilde{W}^0 q\bar{q}$ followed by $\tilde{W}^0 \rightarrow \tilde{B} l^+ l^-$ (or $\tilde{g} \rightarrow \tilde{W}^\pm q\bar{q}'$ followed by $\tilde{W}^\pm \rightarrow \tilde{B} l^\pm \nu$), in particular if the track of the charged Wino is not observable. Thus, it may not be easy to confirm that Wino is the LSP. For the test of anomaly-mediation model, it is important to answer the following questions:

1. How do we determine the masses of gauginos rather than mass differences?

2. How do we know that the lightest state is Wino, not Bino?

These can be easily answered if the (short) tracks of charged Wino can be identified at the LHC [5]. Although it is very challenging, such tracks may be seen in the inner detector, like the semiconductor pixel detector and/or the transition radiation tracker (TRT). If the tracks of charged Winos can be identified, it is obvious that the lightest gaugino is Wino, not Bino. In addition, Wino mass may be determined by using timing information combined with momentum information on the charged-Wino track. The resolution of the determined β is about 0.1 if β is less than 0.85. So the mass can be determined with accuracy of 10%, if we have enough samples of this exotic track.

Even if the information on the charged-Wino track is not available, the above questions may still be answered. For the first question, one way to determine the gaugino masses is to use the cross-section information on the process $pp \rightarrow \tilde{g}\tilde{g}$. As one can see in Fig. 1, $\sigma(pp \rightarrow \tilde{g}\tilde{g})$ strongly depends on the gluino mass. Thus, even if the error in the cross section is fairly large, we may still have a useful constraint on the gluino mass. When the signal number can be determined very roughly with an accuracy of 20 % level, which is the uncertainty of the background, gluino mass can be estimated with an accuracy of 3 %.

In order to discriminate the possibility of Bino-LSP, we may be able to use the Drell-Yan process $pp \rightarrow \tilde{W}\tilde{W}$. If the \tilde{W}^0 is the lightest neutralino, such a process does not provide any signal. If Bino is the LSP, on the contrary, Winos produced by this process decay, resulting in events with large missing E_T and possibly multi-leptons. From the negative search for such event, we may be able to discriminate the possibility of Bino-LSP. Another possibility is to tag the flavor of quarks emitted by the decay of gluino, which may be possible for third-generation quarks. In the Wino-LSP case, the following process may occur: $\tilde{g} \rightarrow \tilde{B}b\bar{b} \rightarrow \tilde{W}^+l^+\nu b\bar{b}$ while, for the Bino-LSP case, $\tilde{g} \rightarrow \tilde{W}^+b\bar{t} \rightarrow \tilde{B}l^+\nu b\bar{t}$. Thus, by identifying the first decay chain using b -jet tagging, we may be able to confirm that the LSP is Wino.

3.5 Testing the anomaly-mediation model

Now we consider how well the anomaly-mediation model can be tested. With the measurements of gaugino masses discussed in the previous subsections, we may be able to check if the gaugino masses satisfy the mass relation in anomaly-mediation model discussed in Section 2.

For this purpose, we first summarize the experimental constraints. For a given set of gluino masses, we plot the regions allowed by the expected LHC constraints on the $m_{\tilde{W}}$ vs. $m_{\tilde{B}}$ plane. Here, based on the discussion given in the previous section, we assume that $m_{\tilde{B}} - m_{\tilde{W}}$ and $m_{\tilde{g}} - m_{\tilde{W}}$ can be experimentally determined with the errors of 1 % (i.e., 2 GeV) from M_{l+l-} and 5 % (i.e., 40 GeV) from M_{l+l-jj} and M_{jj} , respectively. The result is shown in Fig. 6. (Notice that $m_{\tilde{B}} - m_{\tilde{W}}$ is determined so accurately that the upper and lower bounds on $m_{\tilde{B}}$ shown in the figure look almost like a single line.) On the same figure, we also show parameter region which is allowed in the anomaly-mediation model. (See the

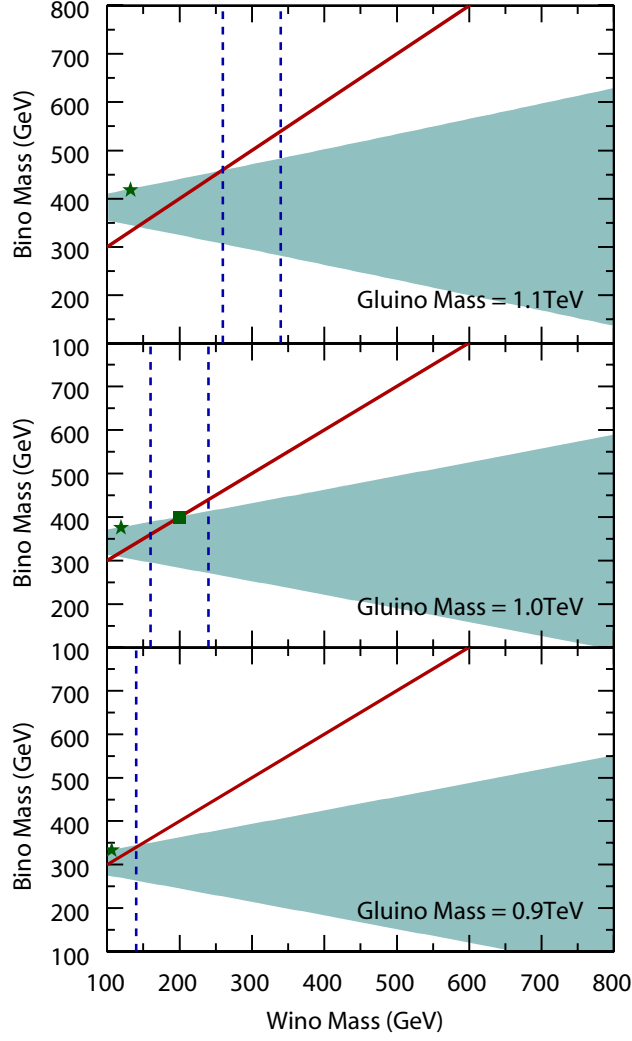


Figure 6: Expected experimental constraints on $m_{\tilde{W}}$ vs. $m_{\tilde{B}}$ plane. The gluino mass is fixed to be 900 GeV, 1 TeV, and 1.1 TeV, from below. Solid lines (which are almost degenerate in the figure) are expected experimental upper and lower bounds on $m_{\tilde{B}}$ as functions of $m_{\tilde{W}}$, while the dashed lines are upper and lower bounds on $m_{\tilde{W}}$. In the shaded region, gaugino masses are consistent with the prediction of the anomaly-mediation model. The square in the middle figure shows the underlying gaugino masses used in our numerical analysis. In addition, with the gluino mass being fixed, the Wino and Bino masses can be calculated in the case of pure anomaly mediation; such point is shown by the star.

discussion at the end of Section 2.) One of the crucial test of the anomaly mediation is to see if those three regions overwrap for a gluino mass consistent with experimental constraints.

The gluino mass should be constrained by using the cross section for the process $pp \rightarrow \tilde{g}\tilde{g}$, as discussed in the previous section. If we can experimentally confirm that the gluino production cross section is consistent with the predicted value for the case of $m_{\tilde{g}} \simeq 1$ TeV, we can conclude that the gaugino mass spectrum is consistent with the prediction of the anomaly-mediation model.

We also note that, in the present case, it is possible to exclude the pure anomaly-mediation model (i.e., $L = 0$). In the case of pure anomaly mediation, the Wino and Bino masses are determined once the gluino mass is fixed. Then, with the precise information on $m_{\tilde{B}} - m_{\tilde{W}}$ from M_{l+l-} , prediction of the pure anomaly mediation can be excluded for the underlying parameter used in the current analysis. In general, accurate determination of $m_{\tilde{B}} - m_{\tilde{W}}$ will be very useful to exclude (or confirm) the prediction of the pure anomaly-mediation model.

4 Summary

In this letter, we have discussed how and how well the anomaly-mediation model can be studied at the LHC. As we have seen, the masses of gluino and Wino may be constrained by using invariant-mass distribution of dijet as well as the cross-section information.

On the contrary, the Bino mass is hardly studied in a large fraction of parameter space since the dominant decay modes of Bino are expected to be $\tilde{B} \rightarrow \tilde{W}^{\pm}W^{\mp}$ and $\tilde{B} \rightarrow \tilde{W}^0 h_{\text{SM}}$. Therefore, it is very difficult to test the gaugino mass relation in the anomaly-mediation model at the LHC. However, in a special case where the sleptons are much lighter than the Higgsino, the decay mode $\tilde{B} \rightarrow \tilde{W}l^{+}l^{-}$ may acquire a large branching ratio. In such a case, the mass difference between Bino and Wino can be well determined by using invariant-mass distribution of dilepton and hence the gaugino-mass relation may be tested.

In any case, in order to confirm that Wino is the LSP, it will be important to find the charged-Wino track. Thus, if the excess of \cancel{E}_T event is observed without the discovery of any sfermions, the search for the short-lived charged-Wino track (with the decay length of $O(10 \text{ cm})$) is strongly suggested.

Note added in proof: The present procedure can be also used in models other than anomaly-mediation model, as far as all the sfermions are heavier than the gauginos. For example, one may test the grand-unified-theory relation among the gaugino masses.

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